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Agricultural Memorandum 893

Relationships between sunshine, Cloud Amounts and Net Long Wave Radiation

Part I. The Diurnal and Annual Distribution of Total and Low Cloud Amounts.

by I Barrie

Introduction

The accurate estimation of short term irrigation need requires a local measurement of rainfall, and a calculation of water loss ("evapotranspiration", Et) from the crop.

This calculation involves, inter alia, the determination of the net radiation at the crop surface. The net radiation can be conveniently split into two components;

1) the net short wave radiation, and

2) the net long wave radiation during a 24 hour period (assuming a daily timestep).

This memorandum notes some of the formulae available for the calculation of the downward component of long wave radiation (RLD) and examines the diurnal variation of cloud amounts with its implications for net radiation.

A set of monthly average correction factors is obtained which will lead towards separate day-time and night-time calculations of net long wave radiation (RL(net)) taking into account the lower values of cloud usually observed during darkness.

Methods of Calculation

Many formulae exist to calculate RLD under clear skies, but perhaps the most generally accepted ones were derived by Brunt (1939) and Swinbank (1963). These are

a) Brunt $\quad RLD = \sigma K_{scr}^4 (a + b\sqrt{e}) \quad W m^{-2} K^{-4}$

b) Swinbank $\quad RLD = -113 + 1.047 \sigma K_{scr}^4 \quad W m^{-2} K^{-4}$

where RLD is the downward component of long wave radiation

σ is Stefan's constant = 5.67×10^{-8} ($Wm^{-2} K^{-4}$)

K_{scr} is the screen air temperature (K)

e is the vapour pressure (mb)

a and b are constants.

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A more recent fomula derived by Brutsaert (1975) is

$$RLD = 1.24\,\sigma K_{SCR}^4 \left(e/K_{SCR}\right)^{1/7}$$

Different researchers have suggested widely varying values for the coefficients, a and b, depending on the ambient conditions at the place and time of measurement, but values of $a = 0.44$ and $b = 0.08$, chosen by Penman (1948), and $a = 0.60$, $b = 0.042$, Baur and Philips (1935), have both been used widely.

The net long wave radiation ($RL(NET)$) can be estimated using Stefan's law to calculate the upward component ($RL(UP)$) and, say, the Brunt equation to calculate RLD leading to

$$\begin{aligned} RL(NET) &= RL(UP) - RLD \\ &= \sigma K_{SCR}^4 - \sigma K_{SCR}^4 (0.44 + 0.08\sqrt{e}) \\ &= \sigma K_{SCR}^4 (0.56 - 0.08\sqrt{e}) \end{aligned}$$

For estimates under cloudy conditions, the formulae are usually multiplied by a factor in the form

$$(x + y(n/N))$$

where n/N is the ratio of actual to possible sunshine and x and y are constants.

Similarly the constants x and y are subject to dispute. Commonly values of 0.1 and 0.9 are used, but Mermier and Sequin (1976) recommended that the cloud cover function should be changed to $(0.3 + 0.7(n/N))$.

Using the Brunt equation in the form

$$RL(NET) = \sigma K_{SCR}^4 (0.56 - 0.08\sqrt{e})(0.1 + 0.9(n/N))$$

Wales-Smith (1979) found a systematic underestimation of net long wave radiation derived from data from Kew, Eskdalemuir and Aldergrove over 7 year periods. He derived empirical factors to compensate for this underestimation.

It is possible that the cloudiness correction in the form that Mermier and Sequin suggest would have yielded better results, but equally a suitable increase in the n/N ratio during the night-time period would go some way to reduce this disparity. This point is investigated in more detail below.

An important aspect in the estimation of $RL(NET)$ is the temperature difference between the screen and the crop surface which Brunt's formula does not consider explicity. Thus during clear nights the surface temperature will often be in the order of 5°C lower than the screen air temperature: conversley during the day surface temperatures are usually higher than screen temperatures. Given good estimates of these differences, suitable corrections to $RL(NET)$ could be calculated. This aspect will be examined in a further memoranda.

The Diurnal Variation of Total and Low Cloud

The most commonly available information relating to cloud cover is the sunshine total for the day. Expressed as the ratio n/N it is frequently used to apply a correction to the clear sky conditions to give an estimate of the reduction in $RL(NET)$.

Cloud cover data were obtained from eight, hourly reporting, Meteorological Office observing sites chosen partly on the grounds of location and partly due to the availability of additional detailed solar radiation data which will be used in further investigations.

Four of the sites could be considered as being coastal, Leuchars, Valley, Aldergrove and Hurn, with the others being inland, Boscombe Down, Elmdon, Cardington and Shawbury.

Different distributions might be evident for the coastal and inland sites and the data were analysed accordingly, in 2 groups of 4 stations.

The diurnal distributions of total and low cloud, illustrated in Fig. 1a, were derived from data taken at 3-hourly intervals. (See Table 1). Low cloud refers to total cloud cover at or below 8000 feet.

It will be seen that the distribution of cloud at the inland sites all follow a very similar pattern with a fairly sharp minimum of cloud at around 00 GMT followed by a marked upturn, reaching a maximum at around 1300 GMT before declining quite sharply again during the late afternoon and evening.

The ranges covered during the 24 hours are all similar at about 0.9 Oktas for low and total cloud cover.

The distributions at the coastal sites, excep Hurn, displayed more diverse patterns. The fluctuations tended to be smaller with a shallow minimum occurring at varying times during the night and a less pronounced maximum during the late morning or early afternoon. The ranges were narrower at about 0.6 Oktas for total cloud and 0.4 Oktas for low.

The exception to this pattern was at Hurn (some ¼ miles from the coast) where a distribution more similar to the inland sites appears, with the marked minimum and maximum occurring at comparable hours and the range up in the region of 1 Okta.

Whether this shows that coastal sites cannot therefore be classified together as one group or whether Hurn alone is not representative of a coastal situation would need a further analysis of more sites. It may have been naive to hope that a site on the East coast of Scotland could produce markedly similar characteristics to another along the South coast of England: the object is to derive a set of constants which can be easily applied to any site to give a reasonable correction to the lower night-time cloud amounts which are clearly evident from the data.

To this end, despite the site to site variations in the distributions, all the stations display the same general trends, not least in the fairly constant difference of about 1 Okta between the average values of total and low cloud, by day and by night.

The diurnal variation of cloud cover was checked on a monthly basis and, except in amount, no significant differences were found from the trends shown in Fig. 1a which were calculated on annual hourly averages.

The variability about the average values of day and night-time cloud cover can be seen in the scatter diagrams (Figs. 1, b, c, d, e), showing, for Cardington and Valley (1979), the day and night mean values of total and low cloud.

These diagrams agree with Fig. 1a, showing a less pronounced variation during the two periods at the coastal site, especially in the case of low cloud where the points looks fairly evenly spread.

Day and Night-time Monthly Averages of Total and Low Cloud

For each of the eight stations the total cloud (hourly) and the low cloud (3-hourly) was, for each month, averaged separately during daytime, night-time and 24 hour periods. These station averages are noted in table 2a/b

To facilitate the analysis the coastal/inland groupings were maintained and the stations from each class averaged to give two sets of data (table 2c). These data are plotted in Fig. 2.

Once again there are similarities between the coastal and inland sites in that the months with the greatest cloud cover are December, January and February, and the lowest cover evident during May, August and September. The sharp increase in cloud cover, by day and night, occurs at all stations during December.

Common to both groups is the tendency for mean values of low cloud during the night to reverse the usual order and exceed the daytime value during December and January.

Discussion

Undoubtably the local station factors influencing the monthly distribution of cloud at a particular site will be apparent in the averages from that site. For example coastal stratus would be expected to show up at the coastal stations during the spring and summer. The inland sites show, in the larger diurnal ranges and more clearly defined peaks and troughs, the more extensive formation of convective cloud during the summer months.

By averaging over all eight sites these local influences should be largely smoothed out, therefore showing the type of distribution found more generally throughout the country, without much loss in accuracy.

At this point therefore there is no clear evidence to lead to a conclusion that different localities show a significant difference, on a scale that would justify separate analysis. Further work, now in hand, could yet produce a basis for such an assumption.

To summarise the data contained in table 2c and give the extent by which cloud cover differs during day and night-time ratios of total cloud (day)/total cloud(night) and low cloud (day)/low cloud night, (ie TCD/TCN and LCD/LCN) were calculated from table 2c.

Table 3 Day to night-time ratios of total and low cloud

	1	2	3	4	5	6	7	8	9	10	11	12
TCD/TCN	1.06	1.08	1.13	1.13	1.13	1.10	1.09	1.14	1.15	1.11	1.11	1.03
LCD/LCN	1.02	1.04	1.10	1.14	1.13	1.13	1.11	1.14	1.13	1.05	1.03	0.97

The use of these ratios together with an estimate of the mean value for day-time cloud cover, (Barrie 1980), allows a simple calculation to be made to give an approximation to the night-time cloud cover.

Any comments or suggestions on this paper should be referred to the author.

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METEOROLOGICAL OFFICE TABLE. 1

Mean Values of the Diurnal Variation of Total and low cloud

period 1971 to 1978

	Hours	00	03	06	09	12	15	18	21		Range		Average	
Boscombe	T	4·82	4·99	5·58	5·79	5·87	5·88	5·56	5·09	✓	1·06		5·45	oktas
	L	4·01	4·28	4·63	4·63	4·78	4·78	4·29	4·01	✓	0·77		4·43	
Shawbury	T	5·27	5·52	5·85	6·03	6·04	6·01	5·72	5·43	✓	0·77		5·74	
	L	4·34	4·70	4·93	5·01	5·09	4·95	4·56	4·36	✓	0·94		4·74	
Elmdon	T	5·27	5·48	5·85	6·03	6·07	6·04	5·71	5·28	✓	0·80		5·72	
	L	4·29	4·65	4·86	4·92	5·00	4·89	4·41	4·14	✓	0·86		4·65	
Cardington	T	5·16	5·43	5·80	6·05	6·18	6·17	5·81	5·35	✓	1·02		5·74	
	L	3·98	4·39	4·73	4·65	4·83	4·83	4·28	3·97	✓	0·96		4·47	
Aldergrove	T	5·50	5·61	5·84	6·10	6·13	6·05	5·77	5·53		0·63		5·82	
	L	4·85	5·05	5·15	5·24	5·20	5·14	4·79	4·76		0·48		5·02	
Valley	T	5·32	5·38	5·76	5·87	5·83	5·69	5·64	5·45		0·55		5·62	
	L	4·49	4·57	4·78	4·81	4·54	4·34	4·33	4·40		0·48		4·53	
Leuchars	T	5·36	5·35	5·59	5·86	5·92	5·88	5·69	5·45		0·57		5·64	
	L	4·44	4·47	4·60	4·50	4·56	4·47	4·29	4·34		0·31		4·46	
Hurn	T	4·62	4·84	5·31	5·55	5·68	5·64	5·38	4·85		1·06		5·23	
	L	3·76	4·06	4·31	4·35	4·63	4·47	3·95	3·74		0·89		4·16	

T ⇒ Total cloud cover

L ⇒ Low cloud cover.

DIURNAL VARIATION OF TOTAL AND LOW CLOUD (ALL MONTHS) FIG-1a

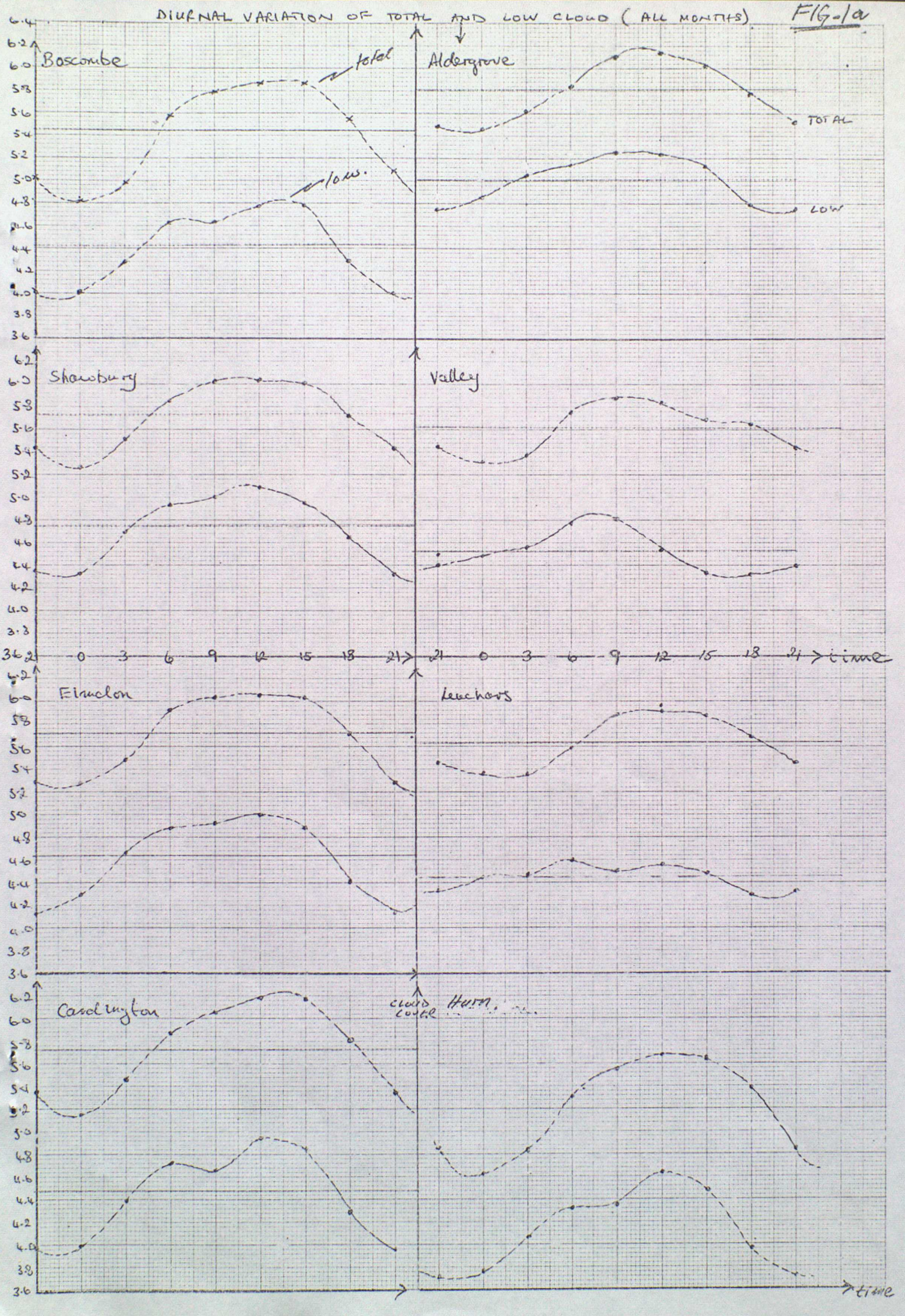


Fig. 1b

CARDINGTON 1979
TOTAL CLOUD.

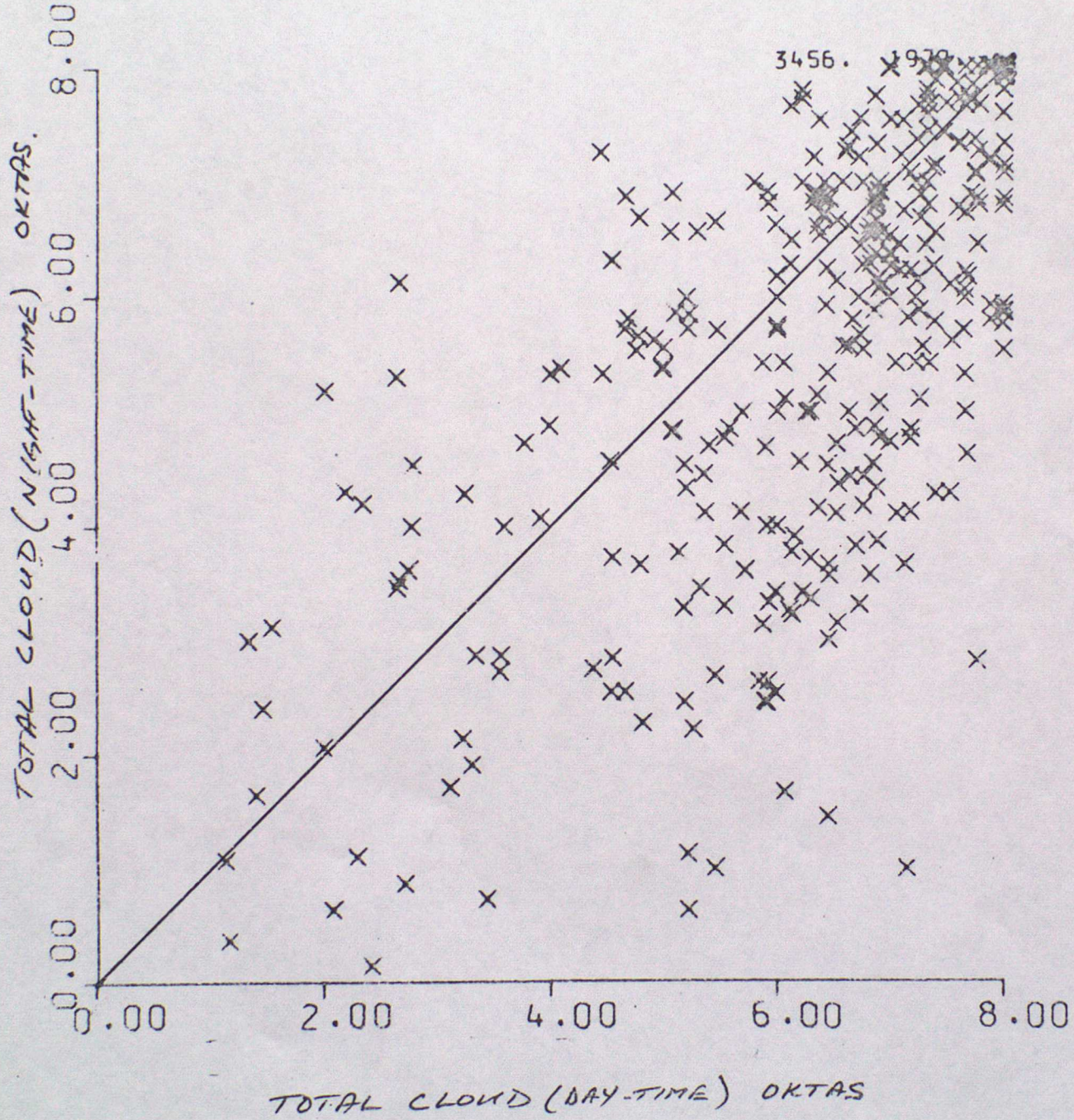
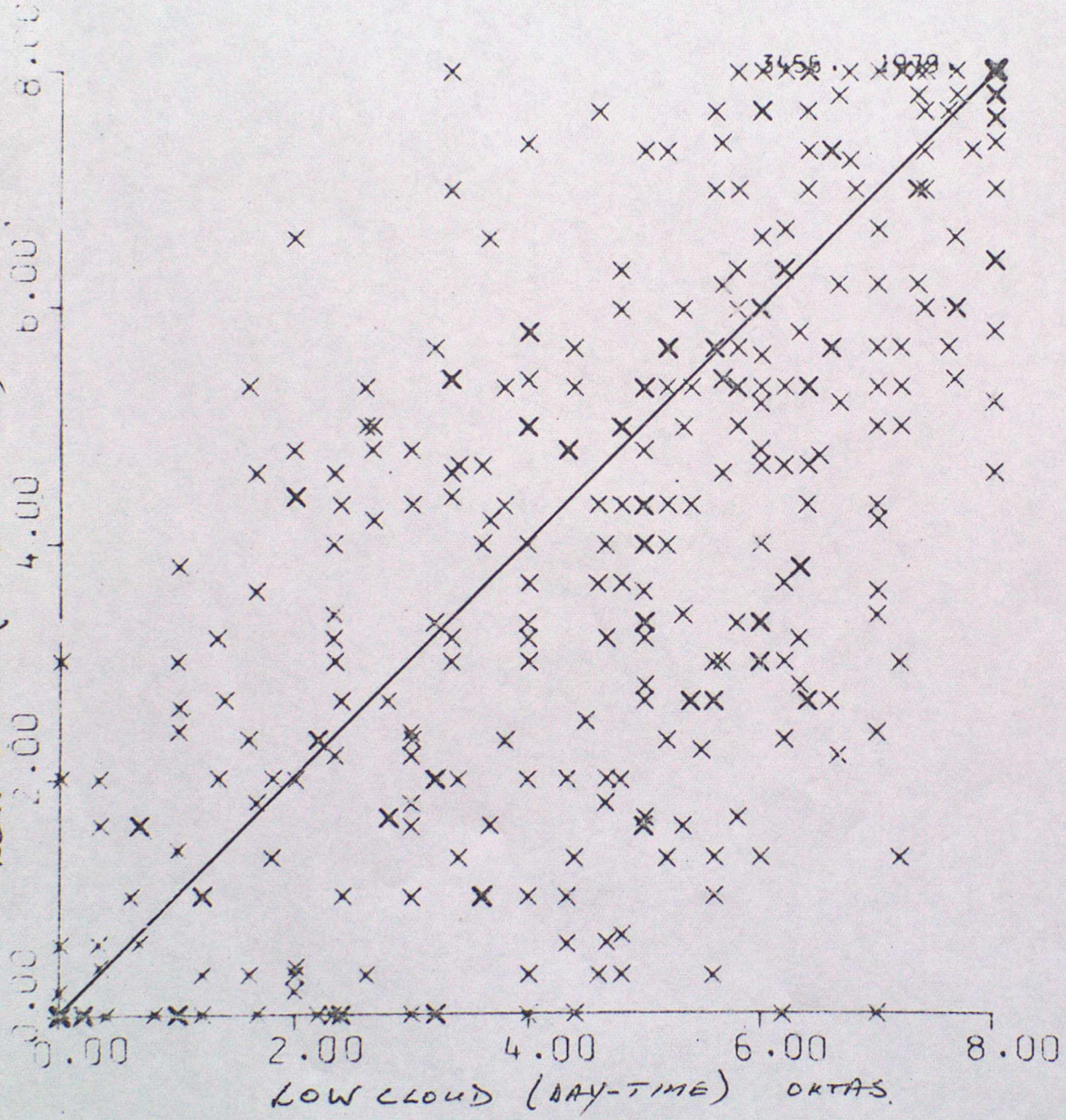


Fig. 1.c.

CARDINGTON 1979

LOW CLOUD.

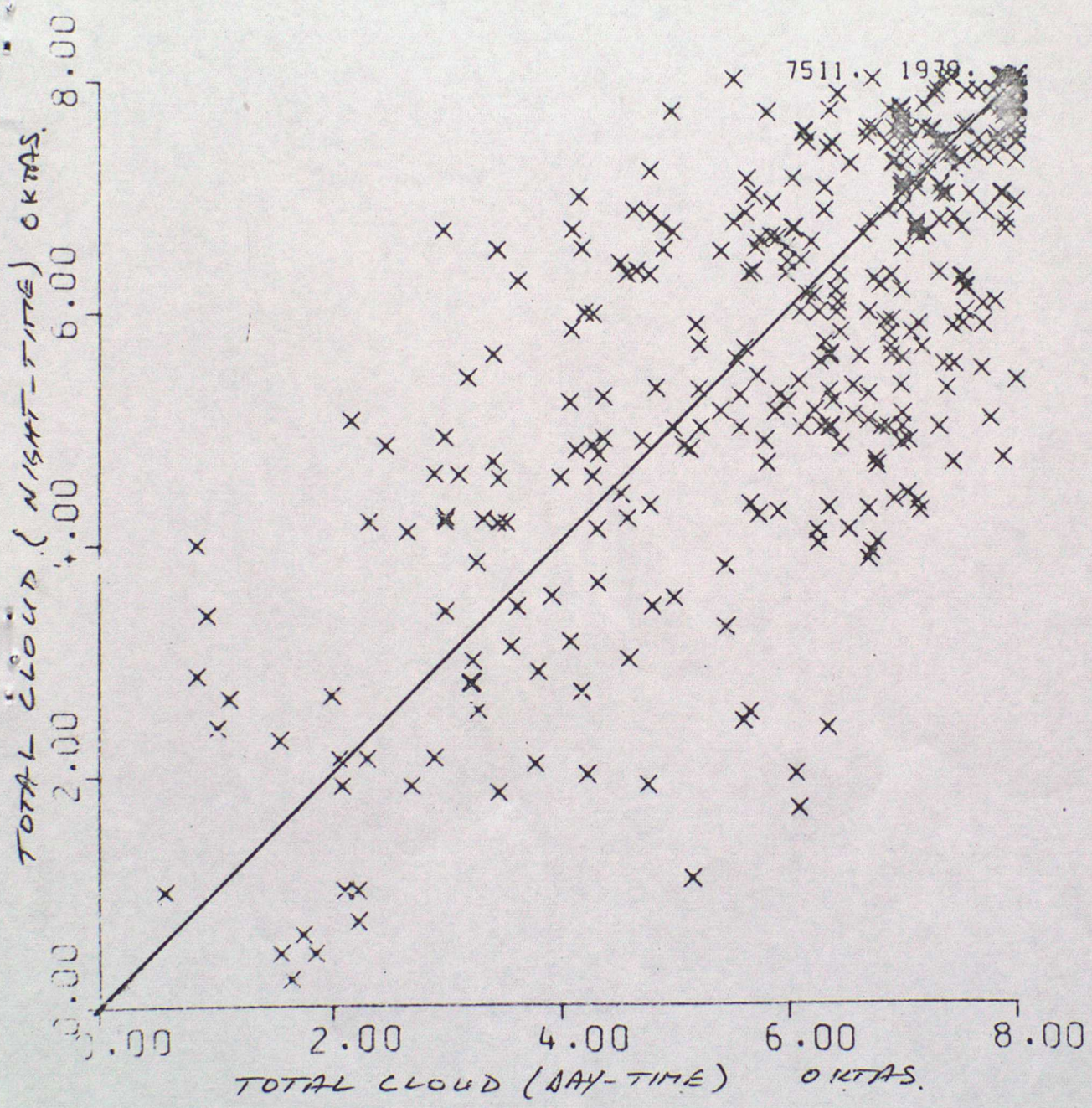


COMPL CLD x CLN

Fig. 1.d

VALLEY 1979

TOTAL CLOUD.

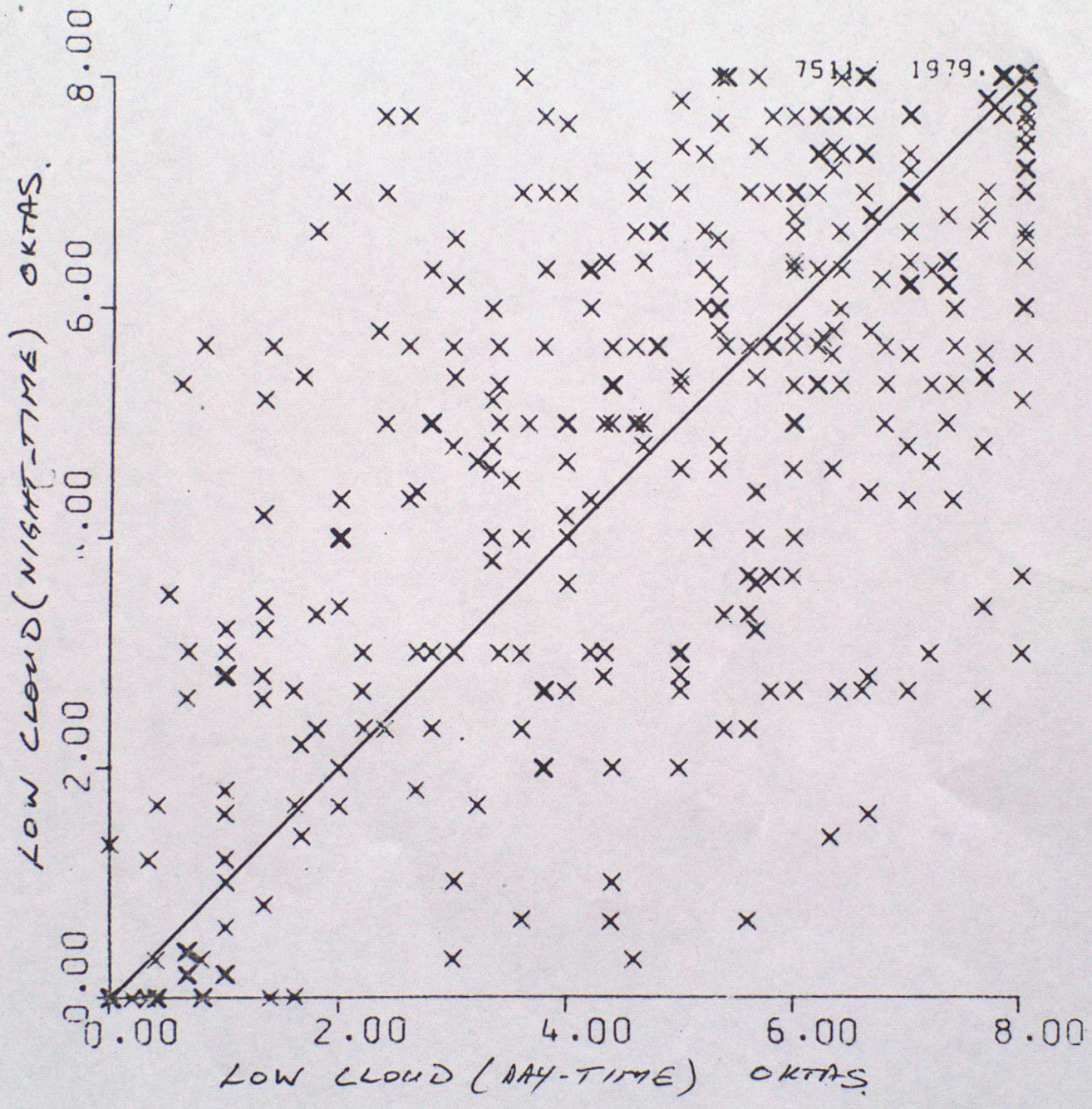


Valley CTD CTH

82-5

Fig. 12

VALLEY 1979
LOW CLOUD.



Valley Low Cloud

2018

MONTHLY AVERAGES OF DAYTIME AND NIGHT-TIME TOTAL AND LOW CLOUD COVER

FIG. 2

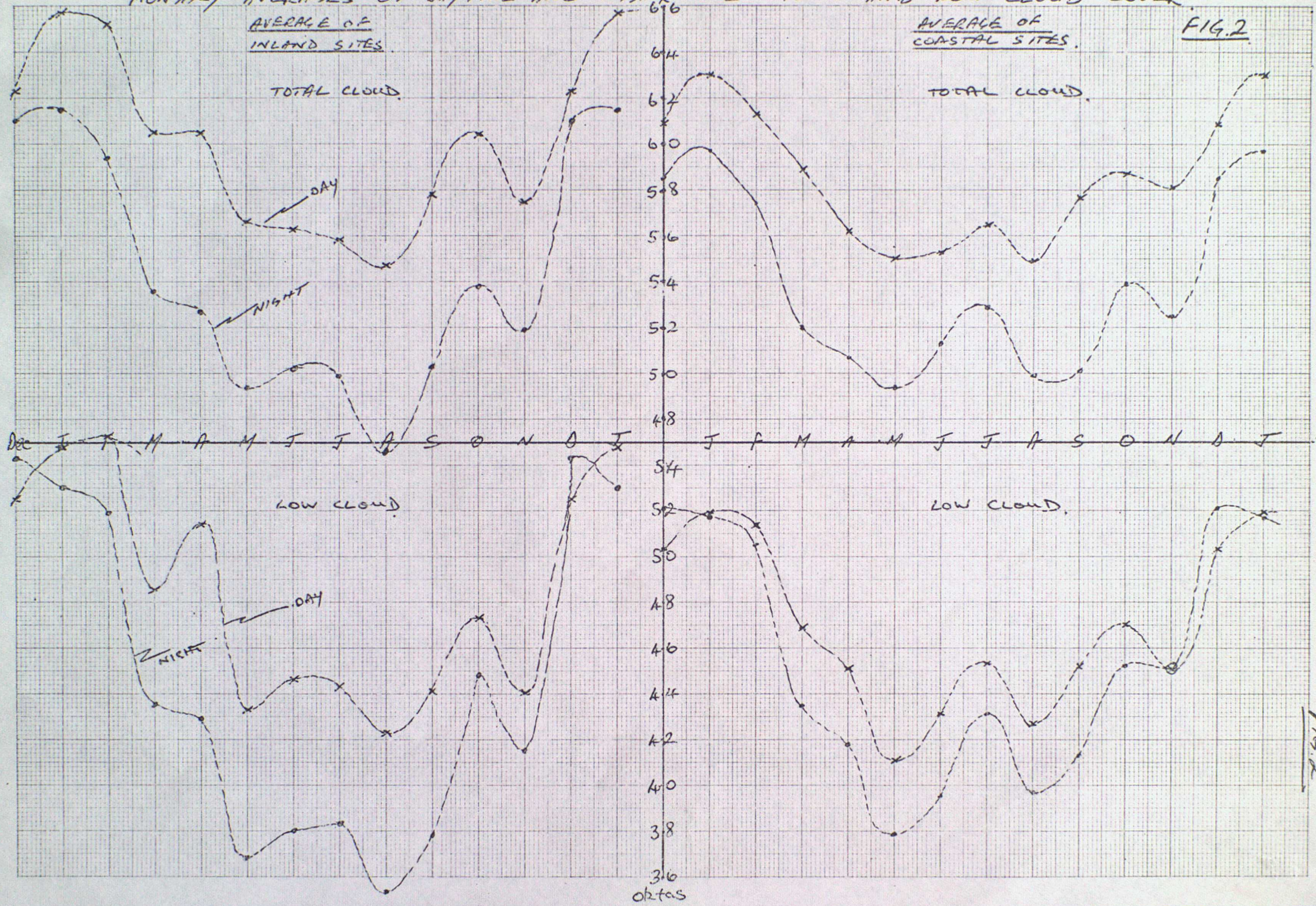


FIG. 2

METEOROLOGICAL OFFICE Table 29

Mean Values of Total and low Cloud during 24 hrs, daytime and night-time (1971-78 averages)

at _____ in oktas.

		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Boscombe Down.	T.D	6.63	6.34	5.88	5.63	5.56	5.47	5.34	5.15	5.43	5.91	5.74	6.24	
	T.N	6.12	5.68	5.11	4.73	4.65	4.67	4.56	4.20	4.59	5.13	5.13	6.00	
	T.24hr	6.29	5.93	5.46	5.21	5.22	5.24	5.11	4.80	5.04	5.49	5.36	6.07	
	L.D	5.70	5.38	4.65	4.59	4.15	4.32	4.17	3.98	4.12	4.72	4.53	5.32	
	L.N	5.42	5.11	4.17	3.66	3.56	3.73	3.48	3.20	3.53	4.43	4.23	5.46	
	L.24hr	5.52	5.21	4.35	4.24	3.93	4.10	3.91	3.69	3.90	4.54	4.34	5.41	
Shawbury	T.D	6.49	6.54	6.04	6.11	5.55	5.60	5.66	5.61	5.98	6.15	5.77	6.21	
	T.N	6.15	6.08	5.48	5.35	4.98	5.19	5.17	4.88	5.30	5.57	5.27	6.21	
	T.24hr	6.26	6.25	5.74	5.76	5.34	5.50	5.52	5.34	5.67	5.83	5.45	6.21	
	L.D	5.49	5.64	5.00	5.28	4.42	4.60	4.62	4.42	4.75	4.94	4.56	5.30	
	L.N	5.39	5.28	4.55	4.36	3.83	4.00	4.21	3.81	4.11	4.70	4.34	5.57	
	L.24hr	5.43	5.42	4.72	4.94	4.20	4.38	4.47	4.19	4.51	4.79	4.42	5.47	
Elmdon	T.D	6.56	6.62	6.05	6.18	5.69	5.68	5.52	5.49	5.85	6.06	5.71	6.23	
	T.N	6.20	6.07	5.47	5.54	5.02	5.05	5.02	4.78	5.11	5.43	5.15	6.16	
	T.24hr	6.34	6.28	5.74	5.89	5.44	5.50	5.37	5.23	5.51	5.72	5.36	6.18	
	L.D	5.44	5.65	4.95	5.36	4.39	4.48	4.46	4.25	4.53	4.82	4.40	5.33	
	L.N	5.33	5.31	4.47	4.69	3.74	3.74	3.88	3.59	3.93	4.50	4.10	5.54	
	L.24hr	5.37	5.44	4.65	5.11	4.14	4.20	4.24	4.00	4.30	4.62	4.21	5.46	
Cardington	T.D	6.60	6.58	6.25	6.27	5.83	5.75	5.79	5.64	5.87	6.03	5.78	6.26	
	T.N	6.13	5.94	5.39	5.47	5.11	5.18	5.20	4.78	5.10	5.39	5.23	6.02	
	T.24hr	6.31	6.18	5.78	5.90	5.56	5.59	5.62	5.32	5.52	5.69	5.43	6.09	
	L.D	5.28	5.44	4.82	5.33	4.38	4.43	4.48	4.26	4.24	4.43	4.14	5.04	
	L.N	5.06	5.06	4.22	4.45	3.60	3.74	3.74	3.37	3.57	4.31	3.91	5.16	
	L.24hr	5.14	5.20	4.45	5.00	4.09	4.17	4.20	3.93	3.99	4.35	4.00	5.12	

KEY :— T => Total cloud / L => Low Cloud / D => Daytime / N => Night-time.
24hr => mean over 24 hours.

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METEOROLOGICAL OFFICE Table 2b

Mean Values of Total and Low Cloud during 24hrs, daytime and night-time in oktas (1971–78 averages)

		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Aldergrove	T_D	6·38	6·26	6·09	5·75	5·76	5·76	6·11	5·92	6·11	6·04	6·04	6·23	
	T_N	6·16	5·91	5·29	5·18	5·11	5·31	5·81	5·29	5·34	5·68	5·55	6·03	
	T_{24hr}	6·23	6·05	5·65	5·49	5·52	5·63	6·03	5·68	5·76	584	5·72	6·09	
	L_D	5·46	5·53	5·13	4·79	4·59	4·84	5·27	5·00	5·19	5·14	5·11	5·52	
	L_N	5·56	5·42	4·60	4·55	4·12	4·33	5·10	4·55	4·76	4·99	5·02	5·57	
	L_{24hr}	5·52	5·46	4·80	4·70	4·41	4·65	5·21	4·83	5·03	5·04	5·06	5·55	
Valley	T_D	6·30	6·02	5·82	5·50	5·19	5·35	5·57	5·41	5·72	5·84	6·22	6·34	
	T_N	6·14	5·85	5·13	4·97	4·90	5·09	5·46	5·06	5·17	5·53	5·81	6·21	
	T_{24hr}	6·19	5·92	5·45	5·26	5·08	5·27	5·54	5·28	5·47	5·67	5·96	6·25	
	L_D	5·24	4·82	4·55	4·32	3·56	4·15	4·31	3·98	4·48	4·68	5·20	5·17	
	L_N	5·30	5·06	4·22	4·03	3·47	3·97	4·37	3·85	4·29	4·60	5·29	5·51	
	L_{24hr}	5·27	5·01	4·34	4·21	3·53	4·09	4·33	3·93	4·41	4·63	5·25	5·38	
Leuchars	T_D	6·08	6·11	5·99	5·85	5·74	5·77	5·80	5·75	6·01	5·94	5·39	5·70	
	T_N	5·65	5·68	5·39	5·67	5·24	5·56	5·52	5·54	5·37	5·42	4·67	5·42	
	T_{24hr}	5·78	5·84	5·67	5·78	5·59	5·71	5·72	5·61	5·72	5·66	4·94	5·50	
	L_D	4·65	4·94	4·70	4·64	4·41	4·28	4·58	4·48	4·50	4·50	3·42	4·40	
	L_N	4·70	5·00	4·60	4·73	4·28	4·16	4·50	4·48	4·28	4·46	3·56	4·58	
	L_{24hr}	4·68	4·98	4·63	4·67	4·36	4·24	4·55	4·48	4·42	4·47	3·51	4·51	
Hurn	T_D	6·44	6·15	5·67	5·38	5·32	5·24	5·14	4·90	5·26	5·66	5·59	6·11	
	T_N	5·95	5·53	4·99	4·46	4·51	4·54	4·38	4·09	4·17	4·92	4·95	5·76	
	T_{24hr}	6·11	5·76	5·30	4·96	5·02	5·03	4·92	4·59	4·76	5·29	5·19	5·86	
	L_D	5·41	5·18	4·37	4·29	3·90	3·96	3·94	3·60	3·92	4·49	4·33	5·04	
	L_N	5·12	4·73	3·99	3·42	3·27	3·34	3·29	3·00	3·21	4·05	4·18	5·19	
	L_{24hr}	5·23	4·90	4·13	3·96	3·67	3·73	3·70	3·37	3·65	4·21	4·24	5·14	

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Table 2c

Ratios ~~Values~~ of Daytime and Night-time Total and Low Cloud.

at 8 1971-78 averages

		Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
average of inland sites	T_D	6.57	6.52	6.05	6.05	5.66	5.63	5.58	5.47	5.78	6.04	5.75	6.23	
	T_N	6.15	5.94	5.36	5.27	4.74	5.02	4.99	4.66	5.03	5.38	5.19	6.10	
	T_{24}	6.30	6.16	5.68	5.69	5.39	5.46	5.41	5.17	5.43	5.68	5.40	6.14	
	L_D	5.48	5.53	4.85	5.14	4.33	4.46	4.43	4.23	4.41	4.73	4.41	5.25	
	L_N	5.30	5.19	4.35	4.29	3.68	3.80	3.83	3.49	3.78	4.48	4.15	5.43	
	L_{24}	5.37	5.32	4.54	4.83	4.09	4.21	4.21	3.95	4.17	4.57	4.24	5.37	
average of "coastal" sites	T_D	6.30	6.13	5.89	5.62	5.50	5.53	5.65	5.49	5.77	5.87	5.81	6.09	
	T_N	5.97	5.74	5.20	5.07	4.94	5.13	5.29	4.99	5.01	5.39	5.25	5.85	
	T_{24}	6.08	5.89	5.52	5.37	5.30	5.41	5.55	5.31	5.43	5.61	5.45	5.93	
	L_D	5.19	5.14	4.69	4.51	4.11	4.31	4.53	4.27	4.52	4.70	4.51	5.03	
	L_N	5.17	5.05	4.35	4.18	3.79	3.95	4.31	3.97	4.13	4.52	4.51	5.21	
	L_{24}	5.18	5.09	4.47	4.39	3.99	4.18	4.45	4.15	4.38	4.59	4.51	5.15	